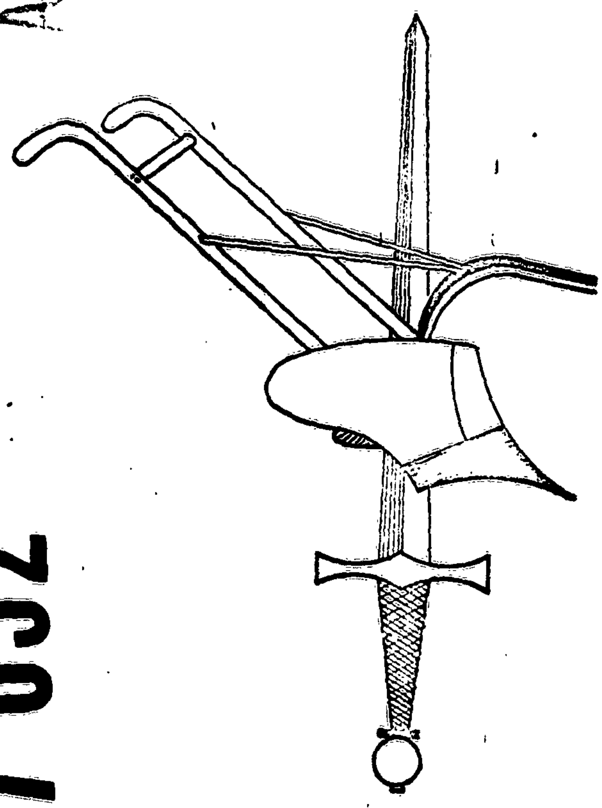
HEADQUARTERS FIELD COMMAND
DEFENSE ATOMIC SUPPORT AGENCY
SANDIA BASE, ALBUQUERQUE, NEW MEXICO

PEACEFUL USES OF NUCLEAR EXPLOSIVES



PROJECT PLOWSHARE

1 September 1962

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FOREWORD

This report summarizes the AEC activity in the peaceful uses of nuclear explosives. The primary effort in this field is being conducted by the Lawrence Radiation Laboratory under the PLOWSHARE program. It is intended that subsequent reports be issued annually, with semi-annual supplements to maintain currency in the basic report. A selected bibliography is included for the reader who desires further information.

This report was prepared by Captain Wilbur C. Buckheit, U. S. Army, a member of the Livermore Division, Field Command, Defense Atomic Support agency.

FOR THE COMMANDER:

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I. INTRODUCTION

A. PLOWSHARE DEFINED

1. The possibility of non-military use of Nuclear Explosives (NE) has been discussed since the detonation of the first nuclear device. The PLOWSHARE program is the study of the industrial and other peaceful uses of nuclear explosives.

2. In February 1957, the first symposium on the Industrial Uses of Nuclear Explosives was held at the University of California Lawrence Radiation Laboratory (LRL). This symposium resulted in the establishment of Project PLOWSHARE. Theoretical studies showed that several projects involving NE appeared to be technically and economically feasible. In addition, areas requiring further experimentation were uncovered. The status of these projects and experiments is reported in this document.

B. BACKGROUND

1. PLOWSHARE studies primarily involve underground nuclear detonations which are either completely contained or which create craters. Table I lists several underground experiments which have been analyzed for information on cratering and containment.

2. Attempts to relate crater dimensions to the depth of burial and the yield of the explosive led to theoretical conclusions that these dimensions must be scaled by the cube root of the yield. Hence, for two different yields, detonated at the same scaled depth of burial*, the scaled crater radius or depth* should be equal. These relationships were derived

---

* Scaled depth $= \dfrac{\text{depth of burial (ft)}}{W^{1/3}}$

Scaled crater radius or depth $= \dfrac{\text{actual radius or depth (ft)}}{W^{1/3}}$

W is yield in kilotons.

For small charges, it is convenient to scale dimensions such that:

λ (lambda) $= \dfrac{\text{depth of burial (ft}}{W(\text{lbs})^{1/3}}$

Unless otherwise indicated, these definitions apply throughout the report.

from dimensional analysis. A suggested refinement considered the one dimensional effect of gravity and predicted that the actual crater dimensions should scale as the one-fourth power of the yield. Experimentation was needed to verify these relationships. Table I lists the underground nuclear detonations in order of increasing scaled depths. (Crater dimension scaling is not shown in this table.)

3. Test experience at the Nevada Test Site indicates that complete containment of radioactive debris from a nuclear device of 20 KT or less can be expected if the depth of burial in the tuff deposits is 450 $W^{1/3}$ feet or greater (where W is the yield in KT). Uncertainties concerning the structural effects on the tuff above the cavities which will be created by detonations of devices larger than 20 KT dictate deeper depths of burial for these larger yields. Computer codes, though not entirely accurate, do indicate that the depth of burial for containment is dependent on the medium in which the device is detonated. Further experimentation is required to improve the computer codes or to establish dependable empirical formulae for various media.

4. Nuclear tests, including several cratering shots at the Nevada Test Site, have yielded information permitting estimates on the amount of radioactive material introduced into the biosphere from yields of 100 KT or less. Fallout prediction depends on the quantity of activity in the initial cloud and the distribution of the activity according to the fall rates of the soil particles that have scavenged the radioactive materials. For prediction of fallout, two particle size groups are used: those particles greater than 40 microns (μ) in diameter and those smaller than 40 μ. The larger diameter group produces the "close-in" radiation fields. The particles in the smaller diameter group fall very slowly and move with the atmosphere to extremely large distances. Figure 1 shows the fractions of activity vented to the biosphere as a function of the ratio of depth of burst to depth of crater and of particle size. Because of the interrelationship between particle size and ratios of depth of burst to depth of crater, the curves as

drawn are not sensitive to the medium in which the crater is produced. The data indicate that, for a depth ratio of greater than 0.3, essentially all activity is contained on the larger particles. At this point, the world-wide contribution becomes negligible. Cratering tests in desert alluvium indicate that near optimum depths of burial which produce maximum crater dimensions also produce depth ratios greater than 0.3. Figure 1 depicts the fraction of gross activity released by a cratering detonation. The distribution of activity by specific isotope and final surface radiation fields can only be determined by calculations for the specific device and meteorological conditions for a given project.

TABLE I

DATA ON UNDERGROUND NUCLEAR DETONATIONS

Event	Yield (W) (KT)	Medium	Depth (D) (Ft.)	Scaled Depth	Measured Radioactivity Deposited on the Surface (%)	Crater Volume (Yds^3)	Crater Volume/KT (Yd3/KT)
JANGLE-ESS	1.2	Alluvium	- 3.5*	- 3.3*	65	1,650	1,400
JANGLE-U	1.2	Alluvium	17	16	80	37,000	31,000
TEAPOT-ESS	1.2	Alluvium	67	63	90	96,000	80,000
SEDAN	100	Alluvium	635	135	5-10	7,500,000	75,000
NEPTUNE	0.09	Bedded Tuff	99	220	1-2	33,000	370,000**
BLANCA	19.0	Bedded Tuff	835	310	0.5	0	0
LOGAN	5.0	Bedded Tuff	830	485	0	0	0
RAINIER	1.7	Bedded Tuff	790	670	0	0	0
TAMALPAIS	0.072	Bedded Tuff	330	780	0***	0	0
EVANS	0.055	Bedded Tuff	840	2200	0****	0	0

*3.5 feet above ground, included for comparison.

**This explosion took place under a sloping surface (1:3 slope), hence crater is probably larger than would be expected on level surface.

***No breakthrough to surface, but radioactive gases in large quantities leaked into tunnel.

****No breakthrough, but stemming failed releasing gross fission activity into tunnel.

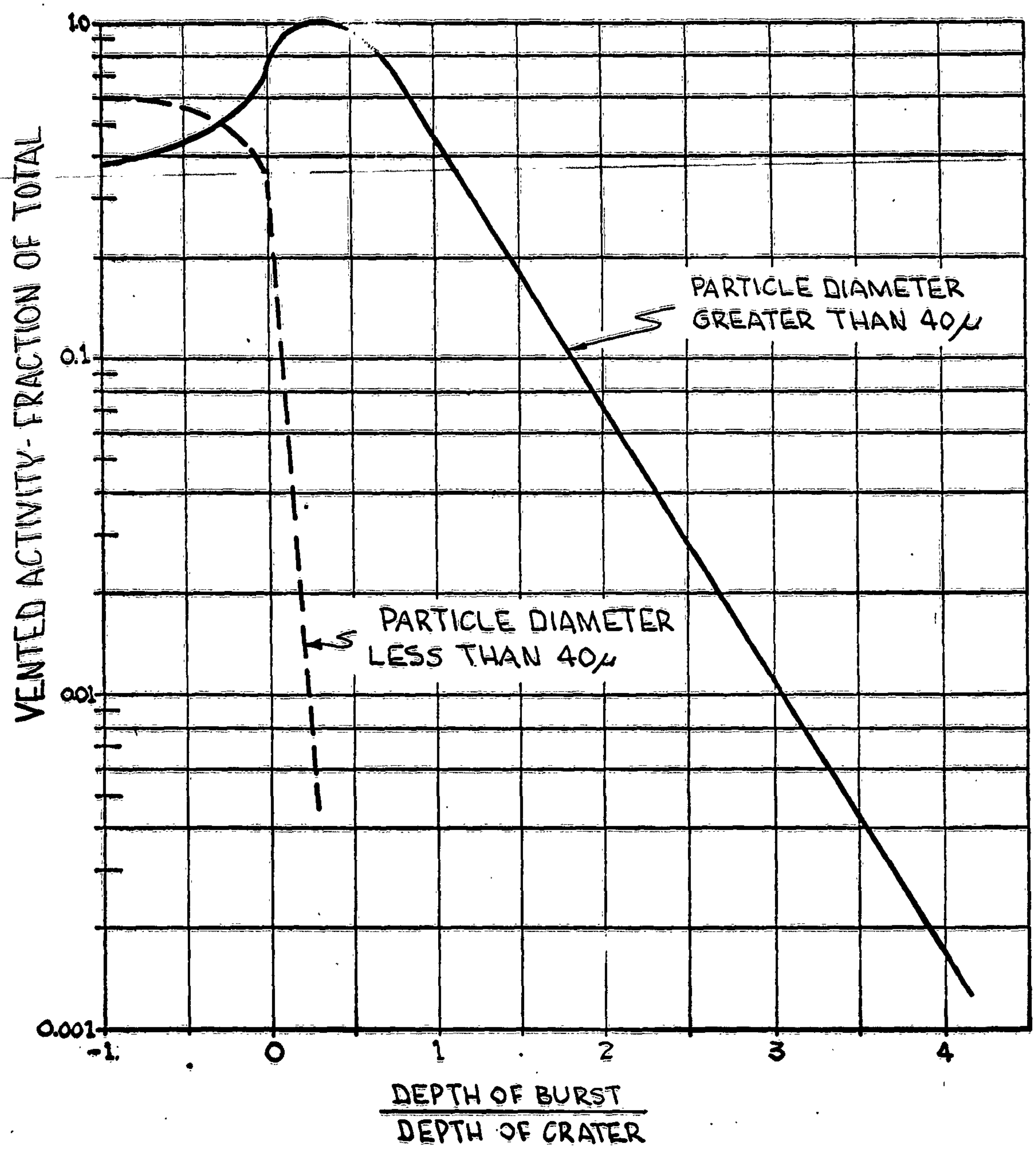


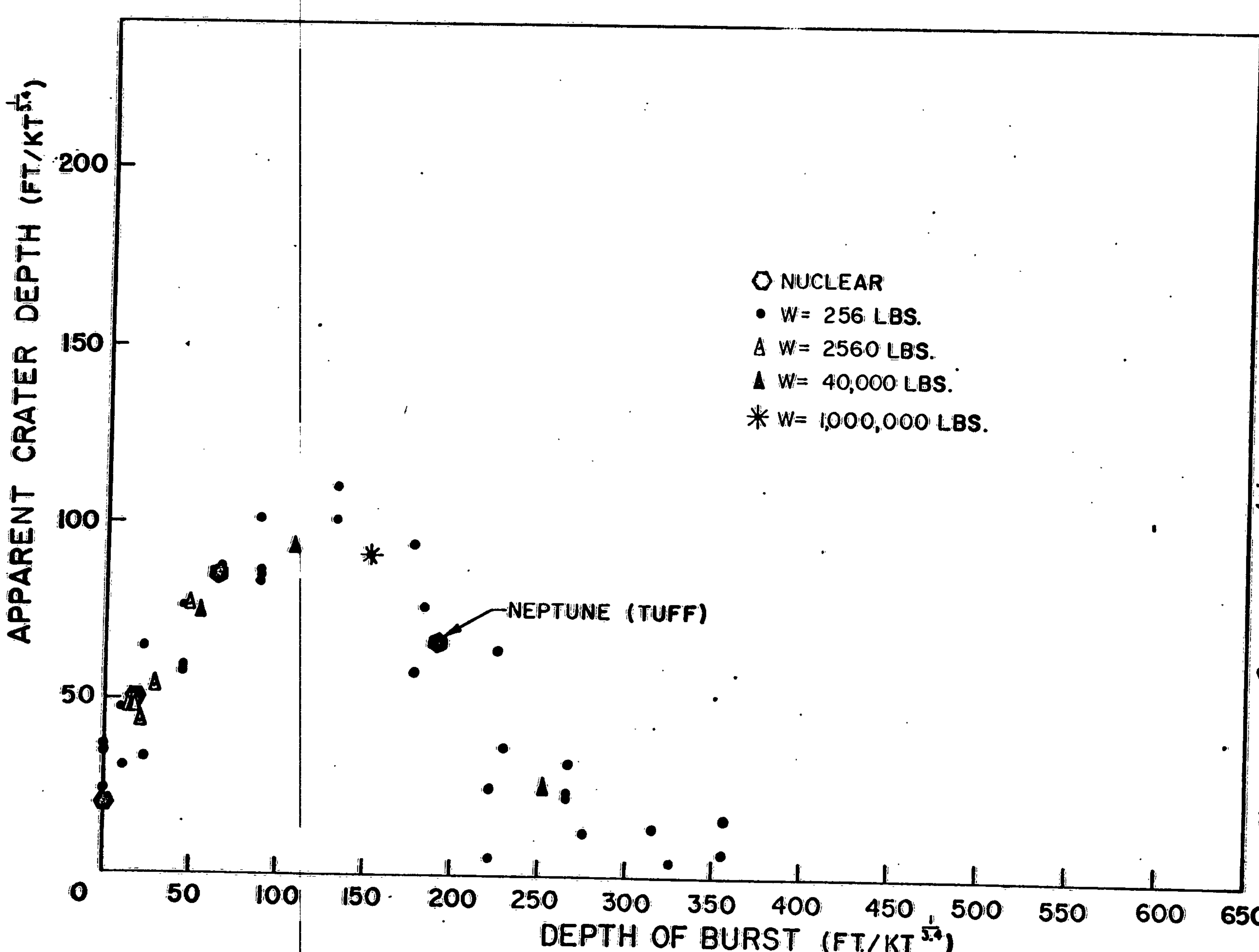
Fig. 1. VENTED ACTIVITY vs RATIO OF BURIAL DEPTH TO CRATER DEPTH

II. PROJECTS

A. EXCAVATION

1. General.

a. Considerable effort, both experimental and computational, has been devoted to the problem of scaling the dimensions of craters produced by large charges of explosives. Much of the experimental work has been done in alluvial soil deposits, primarily at the Nevada Test Site. Using data available from both HE and nuclear detonations shot prior to the 1961-62 nuclear test series, it became apparent that cube root scaling is not reliable over the full range of yields. The best empirical fit of data has been obtained using the expression $W^{1/3.4}$ for kiloton yields in the scaled depth law where W is the charge yield in KT. Plotted on figure 2 are the results of desert alluvium tests plus selected experiments in other media. Figure 3 shows best fit curves drawn through the alluvium data. In addition to the basic crater dimensions obtained from cratering tests in alluvium, preliminary theories on the mechanisms of cratering have also been formulated. When an explosive is detonated underground, the first effects are the crushing, compaction, and plastic deformation on the medium immediately surrounding the charge. A shock wave proceeds outward continuing the process of crushing and displacing material. The behavior of the material will be governed by several critical stresses which vary from material to material. The first critical stress is the dynamic (transient) crushing strength. If the peak shock pressure exceeds this crushing strength, the medium will be subjected to crushing, heating and physical displacement. Below the crushing strength, the material will flow plastically resulting in a large permanent deformation of the material. The medium will continue to respond by flowing plastically until the peak shock pressure falls below the next critical stress of the medium, the plastic limit. Below this stress, the medium response will be small elastic displacements. The peak shock pressure will be attenuated by doing work on the medium and by spherical divergence. If the shock pressure intercepts a free surface, a negative wave is reflected back into the medium. If the resultant shock pressure exceeds



APPARENT CRATER DEPTH (FT/KT$^{\frac{1}{3.4}}$)
DEPTH OF BURST (FT/KT$^{\frac{1}{3.4}}$)
NUCLEAR
W= 256 LBS.
W= 2560 LBS.
W= 40,000 LBS.
W= 1,000,000 LBS.
NEPTUNE (TUFF)
0
50
100
150
200
250
300
350
400
450
500
550
600
650

Figure 2

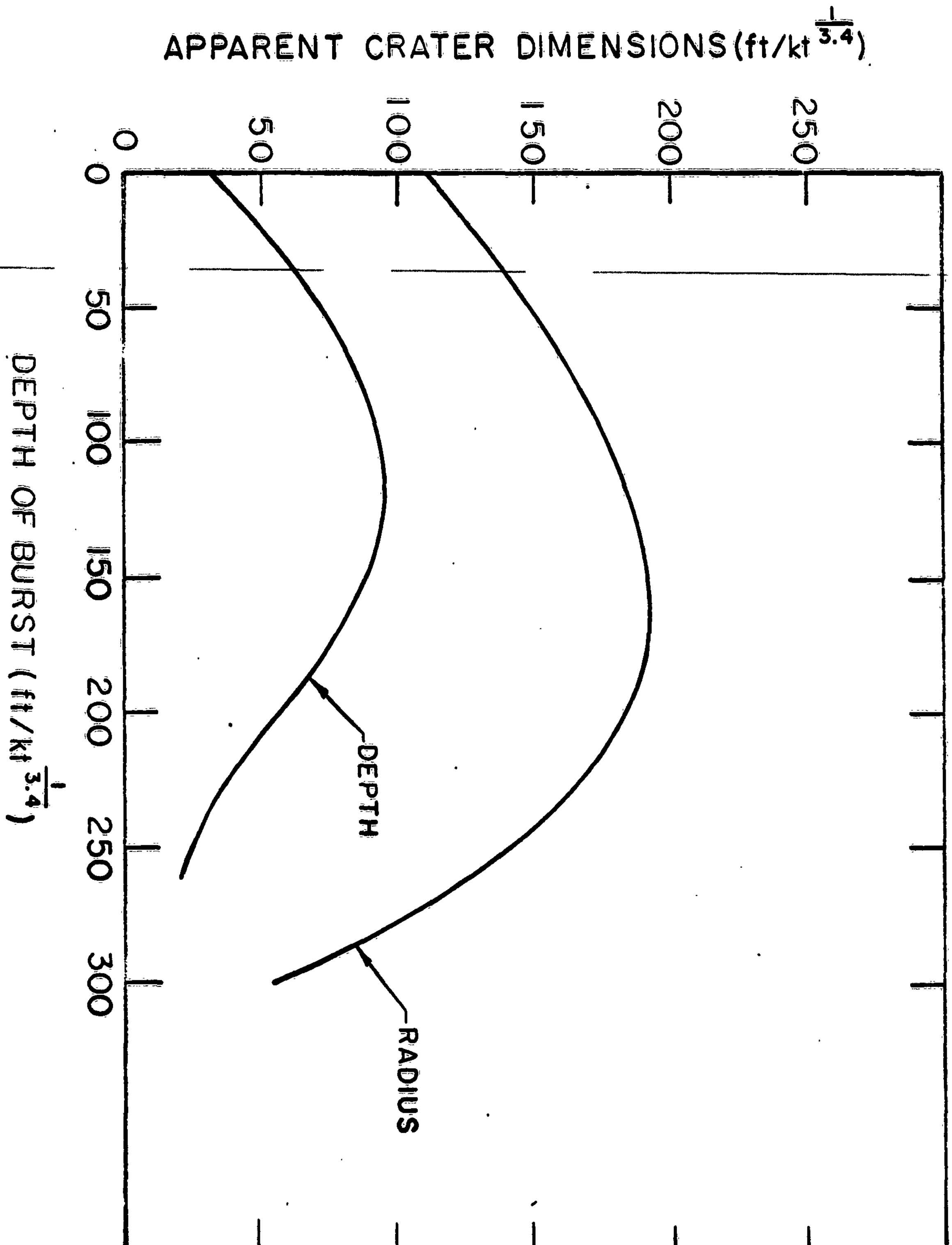

APPARENT CRATER DIMENSIONS (ft/kt$^{\frac{1}{3.4}}$)
0
50
100
150
200
250
300
DEPTH
RADIUS
DEPTH OF BURST (ft/kt$^{\frac{1}{3.4}}$)

Figure 3

the dynamic (transient) tensile strength of the material, the medium breaks up and flies off. The process is called "spall". Another effect results from the formation of gasses in the cavity surrounding the detonation which expand and accelerate particles loosened by other mechanisms. The effects of the various mechanisms are highly dependent on the medium and the depth of burial. For example, the effect of "gas acceleration" of spall particles is pronounced at nearly optimum depths of burial. Here the large earth mass above the blast attenuates the shock pressures to the extent that only low velocity spall particles occur and are then accelerated by the gas. For a shallow depth of burial the spall velocity is very high with the result that gas acceleration plays little part in moving the particles. A final process contributes to the dimensions of the crater that is formed. This is the subsidence of material into the voids created by the compaction and plastic deformation of the medium. This process is most important in very deep explosions.

b. Theoretical calculations indicate there is a relative cratering efficiency between NE and HE. Based on the scaling by $W^{1/3.4}$, the efficiency of NE to HE in alluvium, within the experimental error, is about 90 to 100 percent.

2. Recent Experimentation. The following experiment has provided information of cratering produced by nuclear detonations:

SEDAN -- This PLOWSHARE experiment was detonated on 6 July 1962 in desert alluvium at NTS. The device yielded about 100 KT. The purpose of the experiment was to obtain data on cratering with a large yield device. It was thought that the scaling might more nearly approach $W^{1/4}$ for larger yields. SEDAN was expected to give some indication of the scaling at the higher yields. The device was detonated at a depth of 635 feet and produced a crater about 1200 feet in diameter and 320 feet in depth. These dimensions scale as $W^{1/3.56}$ for radius and $W^{1/3.4}$ for depth. These figures assume that the cratering efficiency between NE and HE in alluvium are approximately equal. The data can also be interpreted as a radius scaling of $W^{1/3.4}$ with an efficiency of about 50 percent. Further experimentation will probably be required to define the scaling at higher yields.

3. CHARIOT.

a. CHARIOT was one of the original projects that grew out of the discussions at the 1957 symposium on the Industrial Uses of Nuclear Explosives. Its purpose is to investigate the technical problems fundamental to excavation by nuclear explosives. In addition to the scientific and operational experience gained, this project was conceived to show the feasibility of creating a usable harbor with nuclear explosives.

b. Early in 1958, attention was focused on a stretch of the Alaskan shoreline, from Nome to Point Barrow. This area has no usable harbors and has a low population density. LRL commissioned the E.J. Longyear Company to make an economic survey to determine the long-term potential of the area and the size of harbor required to support exploitation of the resources of the area. This study resulted in the selection of two possible sites -- one in the vicinity of Cape Thompson and one east of Nome on Darby Peninsula. The Cape Thompson site was selected for its potential growth and the simplicity of operations.

c. The U.S. Geological Survey (USGS) was asked to survey the Cape Thompson area and to recommend specific sites. Three possible sites were recommended. At a conference held in July 1958 and attended by the U.S. Geological Survey, the Atomic Energy Commission, Lawrence Radiation Laboratory, Sandia Corporation, U.S. Army Corps of Engineers, and Holmes & Narver, the Ogoturuk Creek Site was selected as most suitable.

d. Based on the E.J. Longyear study, the original plan was to develop a full scale harbor (1200 yard long channel, 400 yards wide with a turning basin 1000 x 1700 yards) by detonating four 100 KT and two 1 MT devices. Subsequent planning has emphasized the experimental aspects of the operation. If a decision is made to conduct the nuclear detonations, current plans are to detonate four 20 KT and one 200 KT devices.

e. Studies to determine the suitability of the site, the geologic and soil conditions and to determine public health and safety aspects of Project CHARIOT have been conducted at the site since 1958. Yearly operations, called phases, are described briefly below:

(1) Phase I - conducted during the summer of 1958. The program consisted mainly of an on-site survey by the USGS. The study verified that the site was geologically and topographically suitable for harbor construction.

(2) Phase II - Studies were conducted during the summer of 1959 with some field work conducted during the winter of 1959-60. The studies included geology of the area, ground and surface water, coastal processes, meteorology and sub-surface drilling conditions. In addition, the AEC began a program of environmental studies to insure that the public health and safety will be protected.

(3) Phase III - conducted during the summer of 1960 was primarily an extension of the environmental study.

(4) Phase IV - conducted during the summer and fall of 1961 consisted of a continuation of the environmental program and an HE crater study to determine the effect of particle size distribution of the medium.

(5) Phase V - to be conducted during the summer and fall of 1962. This phase will consist of further studies of the environmental program and weather studies. It is anticipated that a comprehensive report on the bio-environmental studies will be published later this year.

f. At the conclusion of the Phase V studies the CHARIOT base camp will be placed in a caretaker status pending further decisions on the conduct of the nuclear detonations.

4. BUGGY.

a. Project BUGGY has been conceived to obtain information on the nuclear cratering effects of a row of charges when detonated simultaneously.

b. The project tentatively envisions the detonation of five small nuclear devices equally spaced at a distance of a crater radius. The tentative location is in desert alluvium at the Nevada Test Site.

c. While there is no approval of this project for either construction or execution, it is hoped that the project can be conducted in 1963.

B. <u>THE RECOVERY OF POWER AND ISOTOPES</u>

1. GNOME.

a. The first nuclear detonation solely for the development of peaceful uses of nuclear explosives was detonated on 10 December 1961. This experiment was known as Project GNOME.

b. Measurements on the RAINIER explosion showed that soon after detonation roughly one-third of the energy was deposited in melted rock at a temperature above 2000°F. In the case of RAINIER, there was a large amount of water present (about 20% by weight), and the surrounding material was permeable to the extent that the temperature was rapidly reduced to that of boiling water. The fact that so much energy was available at such a high temperature led to the idea that firing in a dry medium might store energy long enough to permit efficient recovery. GNOME was developed with this in view.

c. Marine salt deposits are dry; therefore, a nuclear detonation in salt might produce a large volume of melted salt at about 1500°F. from which heat might be extracted. The site finally selected for the experiment was in the Deleware basin salt deposits near Carlsbad, New Mexico (see Figure 4). The salt in the formation averages about 90% NaCl with contaminants of silica bearing materials less than 1%.

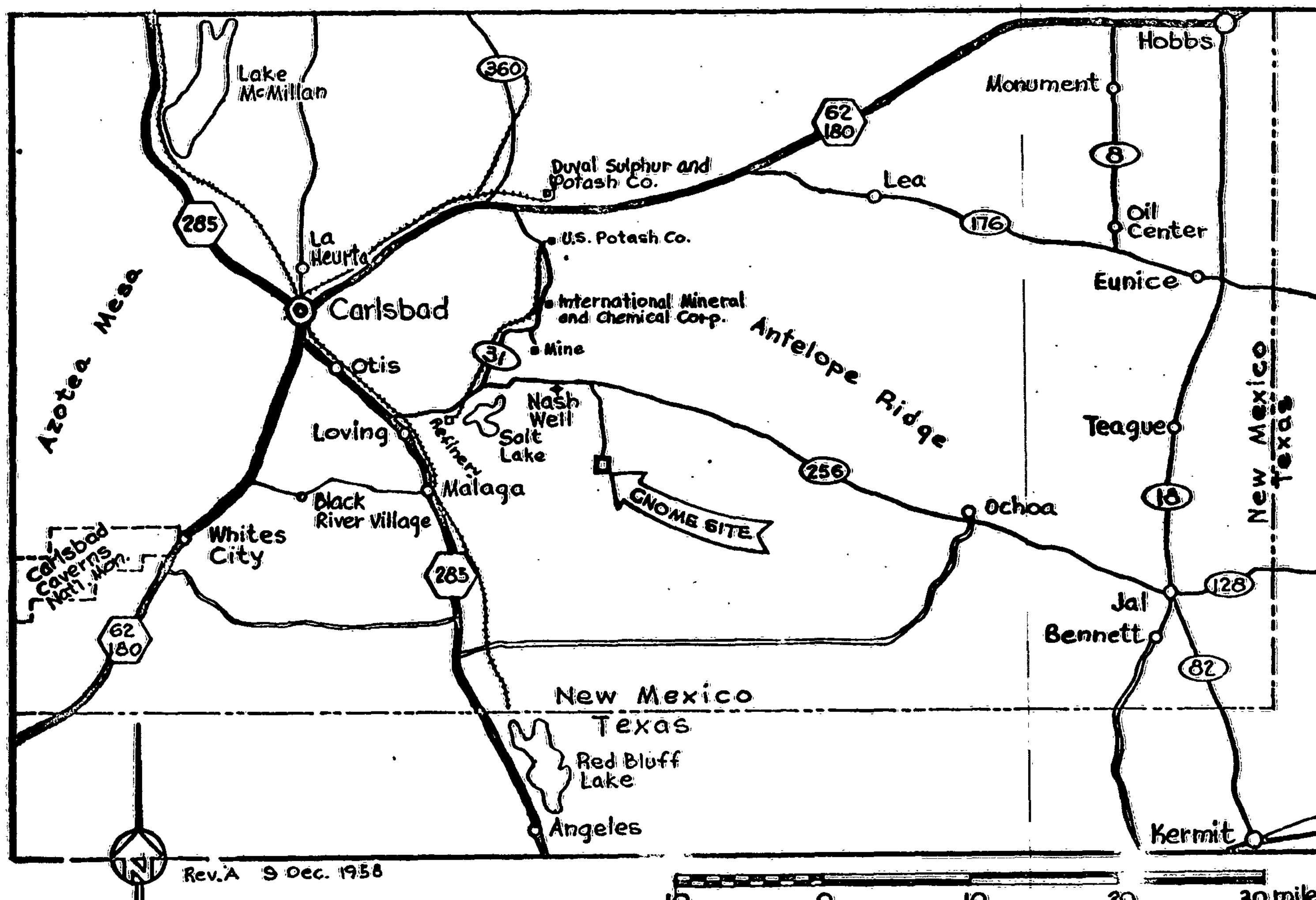
d. The final plans for the experiment were to detonate a 5 kiloton nuclear device at the end of a 1000 foot tunnel, 1200 feet underground to obtain information in the following areas:

(1) Obtain information on the phenomenology of nuclear explosions in a new medium, salt.

(2) Obtain information on the feasibility of recovering energy from a contained nuclear detonation in salt.

(3) Obtain information on isotope recovery from the detonation.

(4) Perform scientific experiments utilizing the high flux of neutrons produced by a nuclear detonation.



MUL-6206

LOCATION OF PROJECT GNOME SITE

FIGURE 4

e. The device was detonated at 1200 PST on 10 December 1961. About 2-3 minutes after the detonation, a cloud of steam appeared at the top of the 1200 foot vertical shaft. The surface radioactivity resulting from the escape of steam rapidly decayed. Subsequent reentry into the cavity showed that the steam escaped when a large plug of salt separating the device from the tunnel was moved by the force of the explosion.

f. Details of the GNOME experiment are the subject of several AEC and Defense Atomic Support Agency reports. A listing of these reports may be found in the references in Section IV of this report.

g. A few pertinent results are listed below:

(1) The detonation produced a cavity which did not collapse.

(2) The average radius is about 80 feet.

(3) The average height of the cavity above the detonation point is about 80 feet. The cavity floor is about at the level of the original detonation point. The lower portion of the cavity is filled with material originally melted by the detonation and which fell from the roof and walls of the cavity.

(4) The escape of steam from the cavity prevented the recovery of energy from the cavity after the detonation.

(5) Attempts at recovering prompt radiochemical samples from the cavity were not successful. Post-shot mining back into the cavity should provide information on isotope recovery.

(6) The neutron wheels were successfully recovered and data are being obtained from these experiments.

2. COACH.

This is a scientific experiment to determine the feasibility of producing and recovering heavy elements with underground nuclear detonations. This experiment appears particularly attractive in that it appears from theoretical considerations that some isotopes may be produced in this way which could not be produced by any other means at least at this time.

Since a salt medium is preferred for isotope recovery, it is proposed that COACH be conducted at the GNOME site and have about the same yield as GNOME, thereby making use of the existing facilities and available environmental data.

C. WATER RESOURCES AND MINING

1. General.

Studies are being conducted to determine the feasibility of using nuclear explosives in the fields of water resources and mining. There are no planned nuclear projects in these fields at this time. Brief descriptions of current thinking in these fields are given below.

2. Water Resources.

a. AQUIFER -- This project name has been given to studies concerned with the development or improvement of water supplies. Among the concepts studied under this program are: the possibility of using nuclear explosives to expose aquifers to available surface water such that the aquifer can be recharged; the possible improvement of the quality of water in areas having inputs of saline water. To eliminate pollution of high quality water, nuclear explosives might be used to divert the saline water sources by creating an off-channel reservoir or by creating a conduit to divert the water through natural mineralized aquifers.

b. A separate program in the field of water resources is the possibility of creating earthfill dams by using nuclear explosives. The study of several natural earthfilled dams has stirred interest in this field.

3. Mining. The large volume of crushed material created by underground nuclear detonations has led to the investigation of mining uses of NE.

The RAINIER event of Operation PLUMBBOB was detonated in a rock formation known as Oak Springs tuff. This tuff is a deposited volcanic ash. The deposit is layered, the beds varying considerably in degree of cementation. The cavity created by the nuclear detonation subsequently collapsed forming a chimney of broken material above ground zero.

The possibility of mining this crushed material by block caving was considered. A pilot plant was constructed in the RAINIER chimney area and was operated during June and July of 1960. The results were presented to the mining industry with the result that several mining companies have begun studies on the use of NE as a means of economically mining low grade ores.

III. NUCLEAR DEVICES

A. DEVICE CHARGES

The AEC has released the following information as to size and charge for nuclear detonations for peaceful uses. The figures apply only to PLOWSHARE and are not to be used for nuclear weapons.

> "The charge for fabricating and firing a device 30 inches in diameter and of a few KT yield, all from fission, would approximate $500,000 when made available in small numbers.
>
> "The charge for fabricating and firing a device 30 inches in diameter of a few 10's of KT yield, all from fission, would approximate $750,000 when made available in small numbers.
>
> "The charge for fabricating and firing a device 60 inches in diameter in the yield range up to 5 MT, of which 5% of the yield was from fission and 95% from fusion, would be approximately $1,000,000 in small quantities.
>
> "These charges are only those incident to the fabrication of the device, emplacing it in its firing location, making the firing attachments, firing, and studies to assure public safety and to determine the results of the detonation. It does not involve such possible activities as preparing a hole or other structure for the firing or studies to determine the results of industrial utility."

B. DESIGN OF NEW DEVICES

LRL is investigating the feasibility of designing special nuclear devices that are more economical or cleaner than those described above. Devices that are to be used in PLOWSHARE projects are not necessarily governed by limitations of weight, size, vulnerability to enemy action and other characteristics of importance to the military. The elimination of these restraints makes possible a completely different class of nuclear devices.

IV. REFERENCES FOR PLOWSHARE PROGRAM

A. BIBLIOGRAPHY

Peaceful Uses of Nuclear Explosives - A Literature Search, TID 3522 (Rev. 5), compiled by Hugh E. Voress, Division of Technical Information, AEC

This document, which is revised periodically, contains an excellent listing of reports, papers and journal literature on the subject of PLOWSHARE. Revision 5 contains 149 references and is recommended as the basic reference for one desiring to read further on the subject of PLOWSHARE.

B. PROJECT GNOME

1. The following reports and their status as of the date of this report are published by the U.S. Atomic Energy Commission:

Agency	Report No.	Subject or Title	Date of Issue
LRL	PNE-101F	Power Studies	To be published
LRL	102F	Isotopes Program	To be published
ORNL	103F	Design of Sequenced Gas Sampling Apparatus	To be published
LRL	104P	Close-In Shock Studies	22 May 62
LRL	105P	Stress Measurements with Piezo-electric Crystals	31 May 62
LRL	106P	Post-Shot Temperature and Radiation Studies	25 Jun 62
LRL	107	Geologic Studies of the Tunnel and Shaft	To be published
SC	108P	Particle Motion near a Nuclear Deto-nation in Halite	15 Mar 62
SRI	109P	Earth Deformation from a Nuclear Detonation in Salt	28 Mar 62
USC&GS	110P	Seismic Measurements from a Nuclear Detonation in Halite	12 Apr 62
SRI	111P	Intermediate-Range Earth Motion Measurements	21 Mar 62
LRL	112	An Investigation of Possible Chemical Reactions and Phase Transitions Caused by a Nuclear Explosive Shock Wave	To be published
LRL	113P	Resonance Neutron Activation Measurements	2 May 62
LASL	114F	Symmetry of Fission in U^{235} at Individual Resonances	To be published
EG&G	115P	Timing and Firing	30 Apr 62
WES	116F	Design, Test and Field Pumping of Grout Mixtures	15 May 62
USWB	126F	Preliminary Report of Weather and Surface Radiation Prediction Activities for Project Gnome; Final Analysis of Weather and Radiation Data	12 Jun 62

Agency	Report No.	Subject or Title	Date of Issue
H&N, Inc.	PNE-127F	Pre-Shot and Post-Shot Structure Survey	31 May 62
RFB, Inc.	128F	Summary of Predictions and Comparison with Observed Effects of Gnome on Public Safety	31 May 62
SC	129F	Monitoring Vibrations at the US Borax and Chemical Company Potash Refinery	27 Apr 62
USGS	130P	Hydrologic and Geologic Studies	May 62
FAA	131F	Federal Aviation Agency Airspace Closure	15 May 62
USPHS	132F	Off-Site Radiological Safety Report	22 May 62
REE Co	133F	On-Site Radiological Safety Report	22 May 62
USBM	134F	Pre and Post-Shot Mine Examination	22 May 62

2. The following reports published by FC/DASA have been received:

Agency	Report No.	Subject or Title	Date of Issue
SC	VUP-2001	Microbarograph Measurements	Jan 1962
EG&G	VUP-2202	Technical Photograph of Surface Motion	Jan 1962
STL	VUP-2401	Shock Spectrum Measurements	June 1962

C. SELECTED ADDITIONAL REFERENCES

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